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X-625-73-166

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NASA TM X

66276

# ION COMPOSITION DURING THE FORMATION OF A MIDLATITUDE E<sub>s</sub> LAYER

(NASA-TM-X-66276) ION COMPOSITION DURING  
THE FORMATION OF A MIDLATITUDE E SUB S  
LAYER (NASA) 14 p HC \$3.00 CSCL 04A

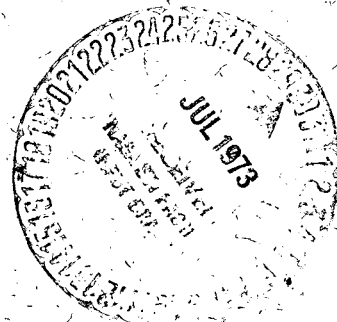
N73-27313

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JUNE 1973



— GODDARD SPACE FLIGHT CENTER —  
GREENBELT, MARYLAND

**ION COMPOSITION DURING THE FORMATION OF A  
MIDLATITUDE E<sub>s</sub> LAYER**

by

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**ABSTRACT**

The positive ion composition within a midlatitude sporadic E layer has been measured with the aid of a rocket-borne ion mass spectrometer launched from El Arenosillo, Spain on July 3, 1972 at 0743 LMT. Ionograms taken before and during the rocket flight showed a developing sporadic E layer near 114 km. Rocket data showed peaks in electron density and metallic ions at this same height. Both the maximum and total content of the metals are observed to be greater on the downleg than the upleg measurement.

## INTRODUCTION

Midlatitude sporadic  $E_s$  is commonly observed on ionograms as a low lying horizontal trace. It is the result of an electron density enhancement in a narrow altitude range in the vicinity of the E region maximum. This enhancement is thought to be caused by horizontal wind shears acting in the presence of the vertical component of the terrestrial magnetic field (Whitehead, 1961, 1962; Chimonas and Axford, 1968). Long lifetime ions (e.g. metallics) must be a part of the ion composition of the  $E_s$  layer to support the wind shear theory. Metallic ions have in fact been observed within  $E_s$  layers by rocket-borne ion mass spectrometers (Young et al. 1967; Narcisi, 1968).

In this work, we report the results of a recent rocket-borne ion mass spectrometer, which was fired into a small  $E_s$  layer apparently during the period of formation. The launching occurred at El Arenosillo, Spain ( $37.1^\circ\text{N}$ ,  $6.7^\circ\text{W}$ ) on 3 July 1972 at 0743 LMT for a solar zenith angle,  $\chi$ , of  $57.1^\circ$ . The rocket reached an apogee of 122.8 km and passed through an  $E_s$  layer on both upleg and downleg 90 seconds later. Metal ions were detected within the  $E_s$  layer.

## INSTRUMENTATION

The Nike-Apache payload consisted of several instruments to measure the properties of the E region. Ion composition was determined by a pumped quadrupole ion mass spectrometer whose characteristics are listed in Table I, (Goldberg and Blumle, 1970; Goldberg and Aikin, 1971).

Electron density was measured by means of the Faraday rotation technique which utilized linearly polarized radio waves at 3.030 and 6.985 MHz propagated to rocket-borne receivers with linearly polarized antennas. Comparison of the absolute period of the rocket spin ( $\sim 5$  cps) with the apparent period observed by the airborne receivers was used to obtain the electron density height profiles (Aikin et al, 1964). The overall electron density measurement probably has an accuracy of at least  $\pm 5\%$  but the downleg data has less height resolution.

Total positive ion density was measured by means of a Gerdien condenser. In order to obtain the upleg ion density profile the Faraday rotation technique was utilized for absolute density and fine structure was resolved by use of a Gerdien condenser. The downleg profile was determined exclusively from the radio propagation experiment. A set of Geiger-Mueller tubes, sensitive to electrons of energy greater than 40 and 100 kev, was also included as part of the payload.

The ion composition data were reduced to absolute values by normalizing the distribution to the total density profile, taking free molecular flow mass weighting effects into account (Tsien, 1946). This is extremely important in the reduction of the downleg data, where results are much more sensitive to mass weighting effects. The mean rocket coning angle was used for aspect correction of the data. Coning

angle variations ( $\pm 2.5^\circ$ ) could introduce fluctuations from the plotted values of as much as 10% for the heavy masses such as  $\text{Fe}^+$ . Above 105 km a background current occurred on each spectrum and this is attributed to soft energetic particles below 15 kev. This current was subtracted from the ion current for each mass prior to normalization.

Care was taken in the vicinity of the  $E_s$  peak to produce a more accurate value for each constituent by adjusting it to the extrapolated value of the ion density,  $N_i$ , determined for the precise height at which the specified constituent was measured. However, the height resolution of the mass spectrometer was 0.8 km near 114 km altitude. This led to inaccuracies for the density maximum determination of each constituent within the layer. A comparison of the relative ionic abundances within the layer with those near 100 km showed similar values (Goldberg and Aikin, 1973) suggesting that the height resolution limit did not produce severe errors in the representation of the distribution within the layer.

## RESULTS AND DISCUSSIONS

Figure 1 shows three ionograms taken before, during, and after the rocket firing. The sporadic E trace indicated a true height near 114 km. This is in agreement with the ion density enhancement at 114 km determined from the rocket experiments. As time progresses the sporadic E layer is observed to be less patchy and more intense. The sporadic

E critical frequencies for the time of the ionograms were 5.2 MHz for 0733 LMT, which was 10 minutes before the rocket firing, and 10 MHz for the ionograms taken at 0745 and 0752. The primary difference between the last two ionograms shown in Figure 1 is the lack of patchiness in the 0752 trace.

The history of the sporadic E layer can be determined by plotting the critical frequency of the layer ( $f_oE_s$ ) as a function of time. This is shown in Figure 2. Also indicated on this figure are the times of rocket transit through the sporadic E layer and the total flight period. There were no ionograms between 0758 and 0815 at which time  $f_oE_s$  had dropped to 4.7 MHz. This time period is indicated by the dashed line. A survey of morningtime ionograms for the two week period prior to launch showed a regular low level occurrence of  $E_s$  with nominal peak values of  $f_oE_s$  between 4 and 6 MHz. However, these ionograms were spaced one hour apart, making it difficult to determine if the short term enhancement of  $f_oE_s$  during the rocket flight was unique in that two week period.

The observed ion composition is given in Figure 3. It is seen that while  $NO^+$  and  $O_2^+$  are the major ions, there are many species of metallic ions present. Included are  $23^+$ ,  $Na^+$ ;  $24^+$ ,  $Mg^+$ ;  $28^+$ ,  $Si^+$ ;  $39^+$ ,  $K^+$ ;  $40^+$ ,  $Ca^+$ ;  $45^+$ ,  $Sc^+$ ;  $52^+$ ,  $Cr^+$ ;  $56^+$ ,  $Fe^+$ ; and  $58^+$ ,  $Ni^+$ . Other isotopes of these constituents were also seen but not shown. There is a well defined enhancement of the metals in the vicinity of

114 km which produces a 50% increase in the total electron or ion density ( $N_1$ ). This corresponds to the sporadic E trace observed on the ionogram.

The width of the metal layer at the  $10^4$  ion density point is less than 1 km on upleg; however, on the downleg portion of the flight illustrated in Figure 3 the width is nearly 2.5 km. This thickening is symmetric between top and bottomside. In addition the downleg maximum of the metallic ion layer was encountered one kilometer below the height for upleg. The downleg data below 110 km are not displayed because of the difficulty in evaluating the necessary mass weighting corrections in the transition region below this height.

The maximum concentration of metal ions within the sporadic E layer is approximately a factor of two larger on the downleg than on the upleg. The major contribution to this enhancement appears to be  $28^+$ , which is identified as  $Si^+$ . Above the  $E_s$  region  $28^+$  behaves differently than the metal ions. Based on this, one can determine the contribution of  $N_2^+$  to the observed  $28^+$  ion density. Metallic constituents other than  $Si^+$  also show an increase in the downleg case. A notable exception is  $Fe^+$ , which may be enhanced but not observed because the spectrometer height resolution prevents an accurate peak value determination. The total content of metal ions on downleg is also significantly larger, as can be seen by both the increased thickness and

magnitude of the layer. Within the sporadic E layer there is less  $O_2^+$  and  $NO^+$  for the downleg than for the upleg.

The upleg and downleg passages of the rocket are separated by 90 seconds in time and 25.7 kilometers in horizontal range. It is not possible to separate temporal from spatial effects and the observed changes in ion composition may conceivably be due entirely to spatial irregularities. If one assumes that the variations in metal content are temporal in nature and that the beam of the ionosonde antenna contains both the upleg and downleg crossings of the sporadic E layer, than additional information can be derived on the formation of the sporadic E layer.

The negligible change in electron density is consistent with the  $f_oE_s$  observed by the ionosonde which indicates no measurable change between the upleg and downleg sporadic E layer during rocket crossing times. However it should be remembered that sporadic E critical frequencies are sensitive functions of the electron density gradient as well as the actual electron density concentration.

At later times Figure 2 shows an  $f_oE_s$  increase to 11 MHz. This is consistent with further enhancement of the metal ions within the sporadic E region. It is not known whether the layer shown on the downleg was simply compressed or if new ions were transported from above and below the sporadic E height level.

Fresh meteoric material may have been added. July 3 was during the time period of the predicted  $\beta$  Taurids meteor shower. Cuchet (1967) has shown that there is a greater probability of midlatitude sporadic E having a critical frequency greater than 8 MHz during periods of enhanced meteoric activity. The present data confirms that  $E_s$  layers are very sensitive functions of the metal ion content.

### CONCLUSIONS

A measurement is presented of the daytime E region ion composition during the period of formation of a midlatitude sporadic E region. Nine species of metallic ions were detected between 85 and 122 km. There was significant enhancement of these metal ions in the vicinity of 114 km at the location of a sporadic E layer as observed from ionosonde data. Comparison of upleg with downleg information showed that the maximum value of metals within the sporadic E layer had increased by a factor of two and the total content by a somewhat larger factor. Shortly thereafter the critical frequency of the  $E_s$  layer attained its maximum value of 11 MHz. The data substantiates the role of metal ions in the formation of midlatitude sporadic E layers.

TABLE 1  
SPECTROMETER CHARACTERISTICS

Characteristic	Value
Entrance aperture diameter (mm)	.742
Rod length (cm)	12.7
Sampling interval (sec)	1.99
Sweep range (AMU)	4 → 96
Time/unit mass (sec)	.0185
RF (MHz)	2.518
Attractive potential (volts)	- 10

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## FIGURE CAPTIONS

Figure 1: Ionograms recorded before, during, and after the rocket flight period, illustrating the  $E_s$  layer formation.

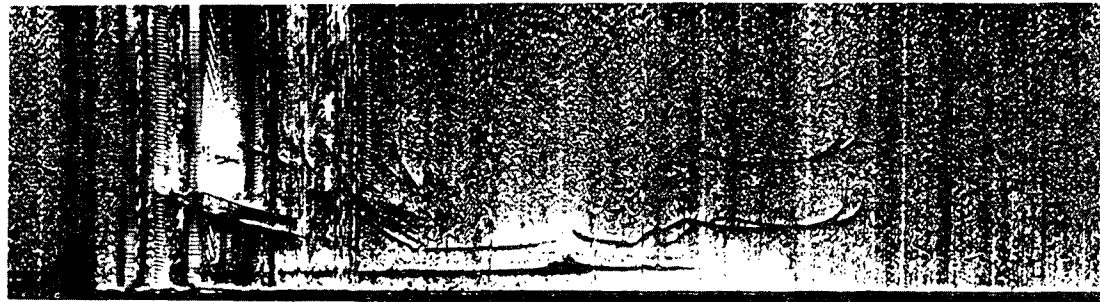
Figure 2: Variation of  $f_oE_s$  during the time period including the rocket measurement. The times of payload transit through the  $E_s$  layer are also indicated.

Figure 3: Observed distribution of positive ion species in the daytime E region on 3 July 1972 over El Arenosillo. Up-leg and down-leg portions of the flight are indicated. The total electron (or ion) density is  $N_1$ .

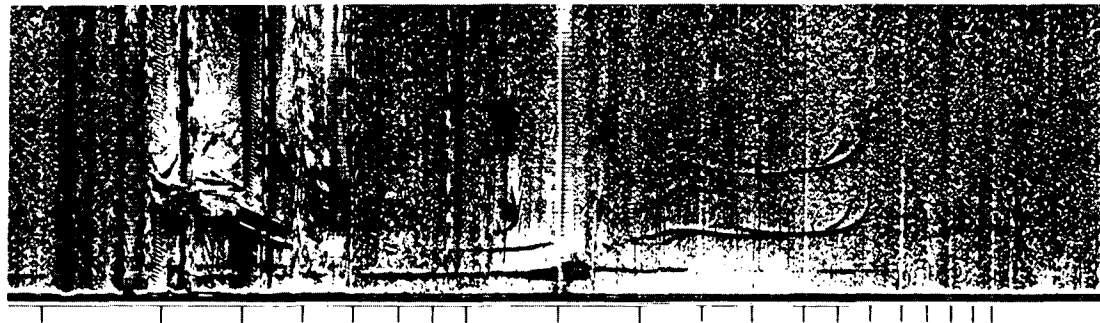
IONOGRAMS  
EL ARENOSILLO, SPAIN  
3 JULY 1973

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LMT  
0733



0745



0752



.5 .75 1 1.5 2 3 4 5 6 7 8 9 10 12 14

FREQUENCY (MHz)

Fig. 1

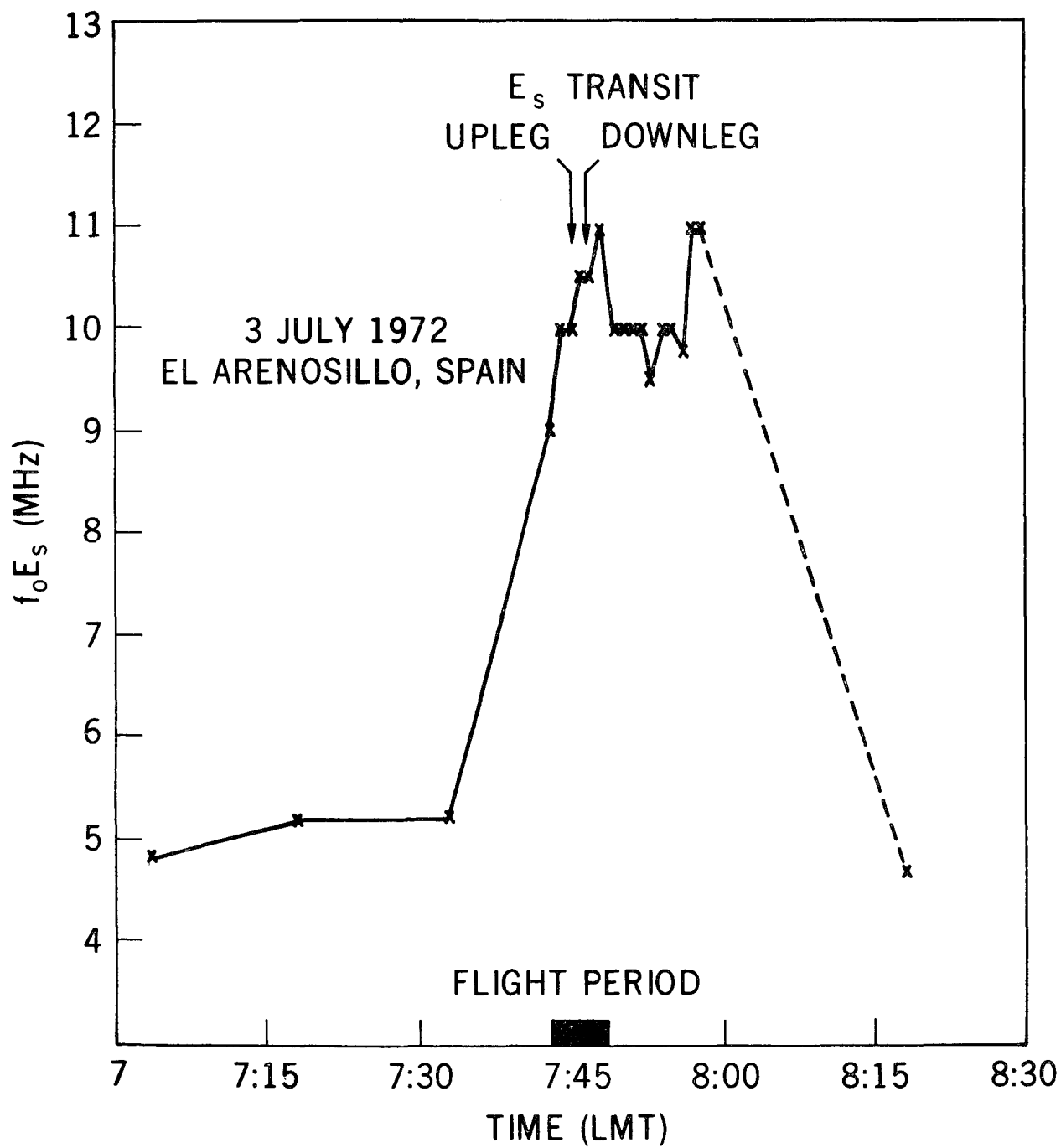


Fig. 2

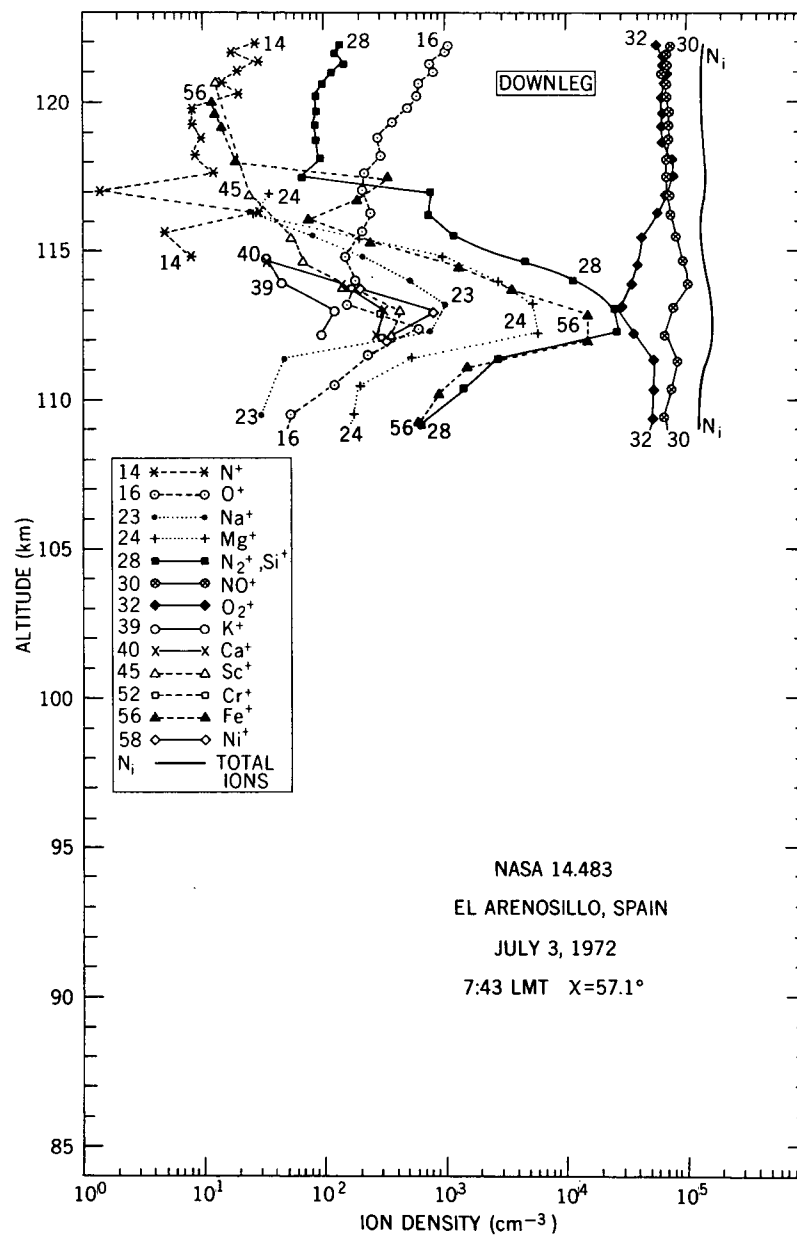
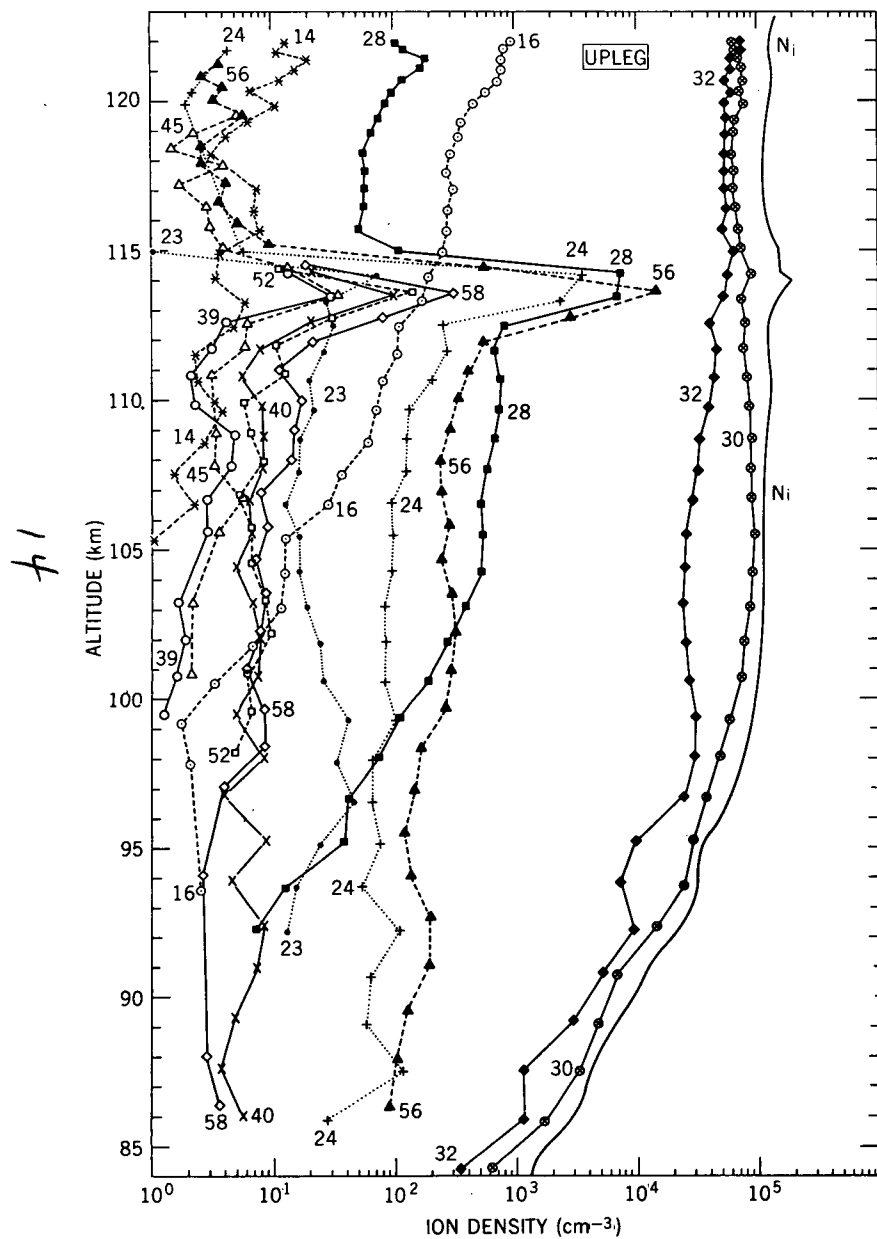


Fig. 3